PROCEEDINGS

OF

THE ROYAL SOCIETY.

May 10, 1894.

The LORD KELVIN, D.C.L., LL.D., President, followed by Sir JOHN EVANS, K.C.B., D.C.L., LL.D., Vice-President and Treasurer, in the Chair.

Professor Dmitri Ivanovitch Mendeleeff, who was elected a Foreign Member in 1882, signed the obligation in the Charter Book and was admitted into the Society.

Mr. Benjamin Neeve Peach (elected 1892) was admitted into the Society.

A List of the Presents received was laid on the table, and thanks ordered for them.

In pursuance of the Statutes, the names of the Candidates recommended for election into the Society were read from the Chair as follows:—

P[illegible]son, William, M.A.
Boulenger, George Albert.
Bradford, John Rose, M.D.
Callendar, Professor Hugh Longbourne.
Cheyne, Professor William Watson, M.B., F.R.C.S.
Froude, Robert Edmund.
Hill, Professor M. J. M., M.A., D.Sc.
Jones, Professor John Viriamu, M.A., B.Sc.
Love, Augustus Edward Hough, M.A.
Lydekker, Richard, B.A.
Penrose, Francis Cranmer, M.A., F.R.A.S.
Scott, Dukinfield Henry, M.A., F.L.S.
Smith, Rev. Frederick John, M.A.
Swan, Joseph Wilson, M.A., F.I.C.
Veley, Victor Herbert, M.A., F.C.S.

The following Papers were read:—

I. "The Composition of Atmospheres which Extinguish Flame." By FRANK CLOWES, D.Sc., Lond., Professor of Chemistry, University College, Nottingham. Communicated by Professor ARMSTRONG, F.R.S. Received March 14, 1894.

1. *Introductory Remarks.*

A study of the experiments which have been made to determine the composition of atmospheres, which act extinctively upon flame, shows that in many cases the atmosphere under examination was in contact with water. The solvent action of water on the carbon dioxide present seems in such cases likely to disturb the composition of the mixture. In other cases, only the proportion of oxygen in the extinctive atmosphere was noted, and the nature of the diluent gas or gases was not taken into consideration. Experiments were also limited to the flames of a few combustible substances, or where a wider range of different flames were tried, the results reported were only of an approximate and relative nature.

The experimental work, the results of which are summarized in this communication, was undertaken in order to supplement the deficiencies referred to above, with the view of drawing further generalisations, and of furnishing support to those already drawn from previous experiments.

2. *Method of Experimenting.*

The mixtures of air with the extinctive gas were made in a glass cylinder, which was closed by a ground glass plate.

A measured quantity of water, equal in volume to the percentage of extinctive gas to be mixed with the air, was first poured into the glass cylinder. The cylinder was then closed by the plate and inverted in a vessel of water. A light xylonite ball of known volume was then passed up, and the extinctive gas was introduced in sufficient quantity to fill the cylinder. The cylinder was then closed and its contents were mixed by the movement of the ball.

In order to test the accuracy with which any desired mixture of gases could be prepared by this method, two mixtures of air with carbon dioxide were submitted to analysis. They furnished respectively 9·8 instead of 10 per cent., and 69·7 instead of 70 per cent. of carbon dioxide.

The experimental flames used were 0·75 in. in height and were gradually lowered into the cylinder, the top of which was finally covered by the plate. The gases were burnt from a platinum jet 1 mm. in diameter.

The gaseous mixture was considered to be in extinctive proportions if the flame was extinguished during its downward passage, or immediately upon attaining its lowest position in the cylinder. The mixture was considered to contain the *minimum necessary quantity* of extinctive gas, when another mixture containing 1 per cent. less of the extinctive gas allowed the flame to continue burning in it for a few seconds only.

The limiting differences between the results of repeated trials corresponded to 1 per cent. of the extinctive gas in the air.

This minimum necessary percentage of extinctive gas is recorded below in tabulated form.

It was considered necessary to take the immediate extinction of the flame as the criterion of extinctive power, since the composition of the atmosphere was rapidly affected by the combustion of the flame.

3. *Influence of the Size of the Flame.*

As a matter of convenience, the flames were, in all cases, set to a height of 0·75 inch. But a series of experiments was undertaken with the same flame of varying size, in order to ascertain if the proportion of extinctive gas necessary to extinguish the flame varied with the size of the flame.

The results of these experiments with flames of hydrogen and alcohol, varying from 0·4 in. to 1·5 in. in height, show that the varying dimensions of the flame, within the wide limits included in the trials, are without influence on the proportion of carbon dioxide in the air necessary to produce extinction.

4. *Method of Preparation of Gases Used.*

The carbon dioxide employed for the experiments was prepared in the usual way by the action of diluted hydrochloric acid upon marble. It was washed with water, and was proved to be practically free from air.

The nitrogen was prepared by heating an aqueous solution containing potassium nitrite, ammonium chloride, and potassium dichromate. An analysis of the resulting gas proved that it contained 99·7 per cent. of nitrogen.

5 *Results obtained by the Experiments.*

In the following table the number entered is the average of numerous closely concordant experimental results. The percentage volume of nitrogen in air is taken as 21.

Combustible substance burnt.	Extinctive proportion of carbon dioxide added to air.			Extinctive proportion of nitrogen added to air.		
	Percentage added.	Percentage composition of mixture. O	: $(N+CO_2)$.	Percentage added.	Percentage composition of mixture. O	: N
Alcohol, absolute....................	14	18·1	81·9	21	16·6	83·4
Alcohol, methylated..................	13	18·3	81·7	18	17·2	82·8
Paraffin, ordinary lamp oil	15	17·9	82·1	23	16·2	83·8
Colza oil with equal volume of petroleum	16	17·6	82·4	22	16·4	83·6
Candle	14	18·1	81·9	22	16·4	83·6
Hydrogen........................	58	8·8	91·2	70	6·3	93·7
Carbon monoxide	24	16·0	84·0	28	15·1	84·9
Methane.........................	10	18·9	81·1	17	17·4	82·6
Ethylene.........................	26	15·5	84·8	37	13·2	86·8
Coal-gas	33	14·1	85·9	46	11·3	88·7

Characteristic differences were observed between the behaviour of wick-fed flames and that of gas-fed flames when they were introduced into an atmosphere which extinguished them. The wick-fed flames gradually diminished in size until they vanished. The gas-fed flames, on the other hand, gradually increased in size, becoming pale and apparently lower in temperature, and then suddenly expired. The extinction of the flame is apparently due in both cases to the lowering of its temperature. This primary cause, however, seems to operate directly in the case of the gas-fed flame, whilst in the case of the wick-fed flame it operates by gradually reducing the amount of combustible gas and vapour produced, and leads ultimately to the flame dying from lack of combustible material. The large expansion of the gas-fed flame is evidently due to an attempt to obtain the necessary supply of oxygen in the diluted atmosphere by increasing its own surface.

6. *Theoretical Considerations.*

The following deductions seem to be warranted by the results arrived at in these experiments :—

1. That the extinction of a flame is not determined only by the *proportion* which the inert gas bears to the oxygen of the atmosphere into which it is introduced, but that the *nature* of the inert gas present also influences the result.
2. That carbon dioxide uniformly exerts a more powerful extinctive effect upon flame than nitrogen does.
3. That there is a remarkable uniformity in the proportions of inert gas which must be mingled with air in order to just extinguish wick-fed flames.
4. That this uniformity does not apply to the flames of combustible gases burnt from a jet.
5. That the flames of gases burnt from a jet show no simple relation, as regards the proportion of oxygen present in the extinctive atmosphere, to the relative proportions of oxygen required for their complete combustion.

With regard to the superior extinctive power of carbon dioxide over that of nitrogen, it has been stated that the greater the density of an inert gas which is introduced into air, the less will be the quantity which suffices to arrest combustion. Waldie suggests that this is due to the cooling effect produced upon the flame by the rapidity of diffusion of its heated products increasing as the surrounding atmosphere increases in density. But it is probable that carbon dioxide also surpasses nitrogen in its extinctive effect upon flame in virtue of its higher specific heat, and because of its slower movement owing to its high molecular weight and density. When

the heavy gas is mingled with the air, it adds to the density of the mixture, and renders the atmosphere more sluggish in its movement towards the flame to supply the necessary oxygen.

It had been anticipated that in the presence of the hydrogen flame, and possibly of other flames, carbon dioxide would have suffered partial deoxidation, as it is well known to do in the presence of burning magnesium vapour. No such action appeared to occur, else the above relation between the extinctive powers of carbon dioxide and nitrogen could not well exist.

The cause of the comparative uniformity of the proportion of extinctive gas required for wick-fed flames has been already hinted at. The flames are starved of combustible nutriment by the lowering of the temperature of the flame. This cause seems to operate with strikingly similar results upon the different solid and liquid combustibles.

The cause of the want of conformity to theoretical considerations in the case of the gaseous flames fed from jets is not at once apparent.

It is of practical interest to note that the introduction of a minimum of 15 per cent. of carbon dioxide into air is necessary to cause it to extinguish ordinary wick-fed flames, the oxygen being reduced by this admixture from the normal proportion of 21 per cent. to 18 per cent. For the extinction of a coal-gas flame, however, the addition of 33 per cent. of carbon dioxide is necessary, and the oxygen being thus reduced to 14 per cent. The hydrogen flame has far greater vitality, requiring the admixture of 58 per cent. of carbon dioxide with air, and the consequent reduction of the oxygen to 8·8 per cent., before it suffers extinction. This fact is of great importance, since it shows that the hydrogen flame in the composite miner's safety lamp ('Roy. Soc. Proc.,' vol. 52, p. 486) may be used as an auxiliary to prevent the loss of flame when the lamp is being carried through mine-air containing large proportions of carbon dioxide.

I have to thank one of my senior students, Martin E. Feilmann, B.Sc., for conducting much of the experimental work involved in this research.

[*April* 28*th*, 1894.—Recent experiments seem to prove that a rabbit can breathe with impunity, for at least an hour, air containing 25 per cent. of admixed carbon dioxide (J. R. Wilson, 'American Journal of Pharmacy,' 50, No. 12). If this is the case, the extinction of an ordinary flame does not prove the surrounding atmosphere to be irrespirable. The introduction of 15 per cent. of this gas extinguishes a flame, whilst the air seems to be still respirable, even after it has been mingled with an additional 10 per cent. of carbon dioxide.—F. C.]